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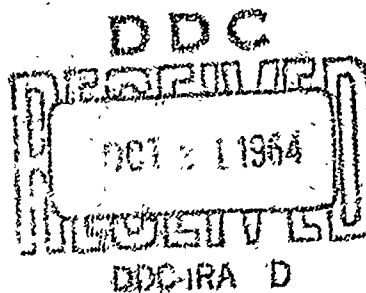
LONG WAVELENGTH INFRARED FIBER OPTICS

INTERIM ENGINEERING REPORT 1

September 1964

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Prepared for

Air Force Avionics Laboratory
Research and Technology Division
Air Force Systems Command
Wright-Patterson Air Force Base, Ohio

Under

Contract No. / AF 33(615)-1952
Project No. 4056, Task No. 405603

Submitted by

Optics Technology, Inc.
248 Harbor Boulevard
Belmont, California

FOREWORD

This report was prepared by Optics Technology, Inc., Belmont, California, on Air Force Contract AF 33(615)-1952 under Task No. 405603 of Project No. 4056, "Long Wavelength Infrared Fiber Optics." The work was administered under the direction of the Air Force Avionics Laboratory, Research and Technology Division, Air Force Systems Command. Mr. A. Prettyman was project engineer for the Laboratory during the first quarter of the program.

This report covers the work performed from June 15 to September 15, 1964 and is the first interim engineering report on the program.

Personnel who have contributed to the program during this period include N. S. Kapany, principal investigator, and R. J. Simms.

ABSTRACT

Work on the development of "Long Wavelength Infrared Fiber Optics" under Contract No. AF 33(615)-1952 during the first quarter is reported. The results of a literature survey for glasses with longer wavelength infrared transmission than arsenic-sulphur glasses are described in detail. The conclusions of this survey are discussed and samples have been obtained of some of the selected glasses. The equipment necessary for this program is described and progress on its fabrication reported.

Preliminary attempts to draw fibers with the available samples using existing fiber drawing equipment have indicated that closer environmental control is necessary to produce seed-free fibers. This was anticipated, and new equipment is now being built. The second quarter will see the completion of all the required equipment and initial work on fiber drawing under more sophisticated conditions.

Publication of this report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

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I. INTRODUCTION

The program for the development of "Long Wavelength Infrared Fiber Optics" is a logical extension of a previous program undertaken by Optics Technology, Inc., entitled "Infrared Fiber Optics Investigation". Under the previous program the techniques for fabricating fiber optics devices from the arsenic-sulphur glasses for use over the wavelength range 1 to 12 microns were developed. The current program has as its aim the extension of the wavelength range of fiber optics to cover, as a minimum, the 8 to 14 micron range. The end result of the program will be the production of fiber optics components for use through the atmospheric window at 8 to 14 microns with an intended overall infrared transmission range of 1 to 18 microns. This program will open a new wavelength range with consequent new applications for fiber optics.

The first quarter has been spent on the following:

1. A survey of both classified and unclassified literature and of all other relevant sources to establish data on glasses which transmit at wavelengths beyond the limit of the arsenic-sulphur glass. The survey was followed by a selection of those relevant glasses potentially suitable for the fiber optics technologies.
2. Contact was made with the organizations which have produced these selected glasses, samples and quotations were requested and in two instances orders have been placed for specific glasses. Correspondence has also been initiated with alternative sources who either could contribute to the technical understanding of the properties of glasses that transmit in the required ranges or who may be future suppliers of glass.

3. Several pieces of equipment for use in this program were designed and their fabrication initiated. The mechanical work on the fiber drawing machine is complete; one of the two furnaces is installed and work is beginning on wiring the power supplies and associated electronics. A concentric crucible furnace is being constructed for the production of flexible fibers and will be used with existing fiber winding machinery. It is hoped that this furnace will provide the design information or will itself be used in the second furnace in the fiber drawing machine under construction.

A motorized goniophotometer table has been constructed and will be used to record the radiation patterns and measure the spectral transmission of fiber optics components. The design of an optical condenser for recording spectral transmission profiles has been finalized and construction of the condenser will begin in the near future.

4. Attempts have been made to draw coated fibers from several glass combinations using the samples of far infrared transmitting glasses supplied by the sponsor at the beginning of this program. The results of these experiments are discussed later in detail.

II. TECHNICAL DISCUSSION

A. Literature Survey

Relatively few workers have been, or are, active in the area of long wavelength infrared transmitting glasses and it was clear during the literature survey that the copious cross referencing used by individual authors encompassed the majority of the literature on this subject. Abstracts, indices and contents of all potentially relevant journals and sources were searched for references concerned with the properties of non-oxide vitreous systems. A Russian group headed by Kolomiets has contributed several papers on the semi-conducting properties of these glass forming systems and, although the optical properties were qualitatively reported, not much of the information was relevant.

The pertinent organizations that have been concerned with these glasses are the following:

1. Servo Corporation of America, Hicksville, Long Island, New York;
2. Texas Instruments, Dallas Texas;
3. Royal Radar Establishment, Malvern, England;
4. IBM, Oswego, New York;
5. Jena Glaswerk Schott, Mainz, Germany;
6. Central Electricity Research Laboratory, Leatherhead, England;
7. RCA Laboratories, Princeton, New Jersey;
8. Bell Telephone Laboratories, Murray Hill, New Jersey;
9. Baker and Adamson, New York, New York;
10. A. O. Smith Corporation, Milwaukee, Wisconsin.

The major portion of the literature relevant to non-oxide vitreous systems has originated from these sources and it was clear that the field of interest fell into two separate areas. The first, which was less relevant to this program, was an interest in their use for encapsulating electronic components, and little data was reported on their infrared transmitting properties. The other category was more directly concerned with the optical properties of these glasses. Sources 4, 7 and 8 fall in the former category, 9 and 10 are no longer active in this field and the rest have done more relevant work.

Twenty-three major glass forming systems are reported in the literature concerned with infrared transmission which exhibit substantial infrared transmission at wavelengths greater than the longest presently obtainable with oxide glass forming systems. These are individually examined in the appendix, in which the more promising systems are selected and the problems relevant to each and the action being taken are discussed in detail. The sources which can most readily supply glasses which are considered to be potentially usable for this work are Servo Corporation and Texas Instruments; quotations have been requested for individual glasses from both companies. Prior to submitting these requests for quotation, a trip was taken to both companies to discuss the properties and problems of the respective glasses, and valuable information beyond that published in the reports was obtained. Some samples of the Servo glasses were available from Wright-Patterson Air Force Base early in the program and these have been used for trial fiber draws which will be discussed later. As a result of quotations two glasses (62-73 B and 62-75 B) have been ordered from Servo. Two glasses (Melt Numbers

165 and 177) of the germanium-arsenic-tellurium glass have been ordered and received from Texas Instruments. The action taken with respect to alternative supplies and different glass types and the expected results are discussed in the appendix.

B. Fiber Drawing Equipment

The major equipment being constructed for this program is a double furnace fiber drawing machine. This machine has one furnace for drawing single fibers from concentric crucibles and a second furnace for drawing multiple fibers from a multiple fiber assembly, and both are incorporated in a single frame with a single bank of temperature controllers to control whichever furnace is in operation. This fiber drawing machine contains the results of the experience gained during the previous program and of the wide experience at Optics Technology, Inc. in fabricating drawing machines for a variety of uses. Since the design of the concentric crucible side of the furnace has not been finalized, a description of this machine will be given in a later report.

In addition to this machine the construction of a concentric crucible furnace is underway. The crucibles will be heated by flexible heating tapes to enable more precise temperature control of the different sections of the furnace and internal inspection can be made during the drawing process through an outer, thick glass wall. Initially, this furnace will be mounted in an existing flexible fiber drawing rig and evaluated with the arsenic-sulphur glasses already available at Optics Technology. This procedure will also be used with the new crucible designs since the properties of the arsenic-sulphur glasses are well known thus limiting the

uncertainties to the crucible rather than to the glass. This flexible fiber drawing furnace will either be used in the fiber drawing machine, if it proves suitable, or will form the basis for the design of a suitable furnace for this machine.

Several small concentric crucibles were made during this quarter and have been used with samples of the Servo glasses available at the start of this program for the production of coated fibers. These crucibles were used in the furnace which proved suitable for the arsenic-sulphur glasses but the problems peculiar to the longer wavelength transmitting glasses prevented the production of high quality fibers.

C. Optical Equipment

The optical evaluation of the fibers and fiber optical components during this program will be based on techniques developed during the previous year. A new goniophotometer table has been constructed for use on the existing equipment and is now ready for the evaluation of suitable samples. This table is motorized and is designed to minimize stray light problems, so that the results should be both more accurately and more quickly recorded than with the previous goniophotometer. Figure 1 shows a diagram of the new attachment.

The optical evaluation equipment is based around a Perkin-Elmer Model 13 Spectrophotometer. This spectrophotometer was overhauled at the beginning of the program. The delivery of a KBr prism, to extend the range beyond the 14 micron limit of the present NaCl prism, is now being awaited.

The basic spectrophotometer was used to record the spectral transmission of the three bulk samples of Servo glass, the results of which are shown in Figure 2.

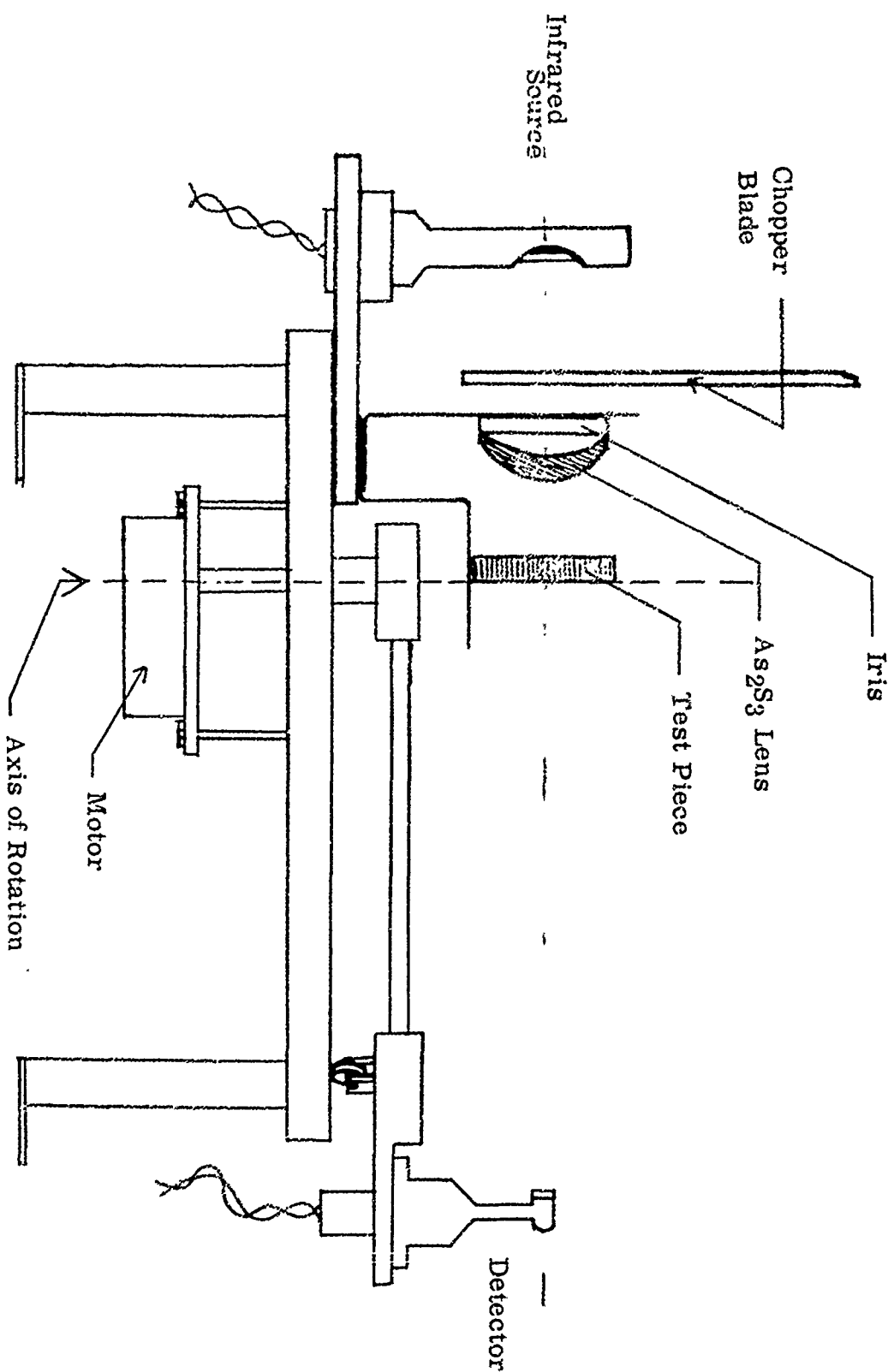


Figure 1 - Goniophotometer

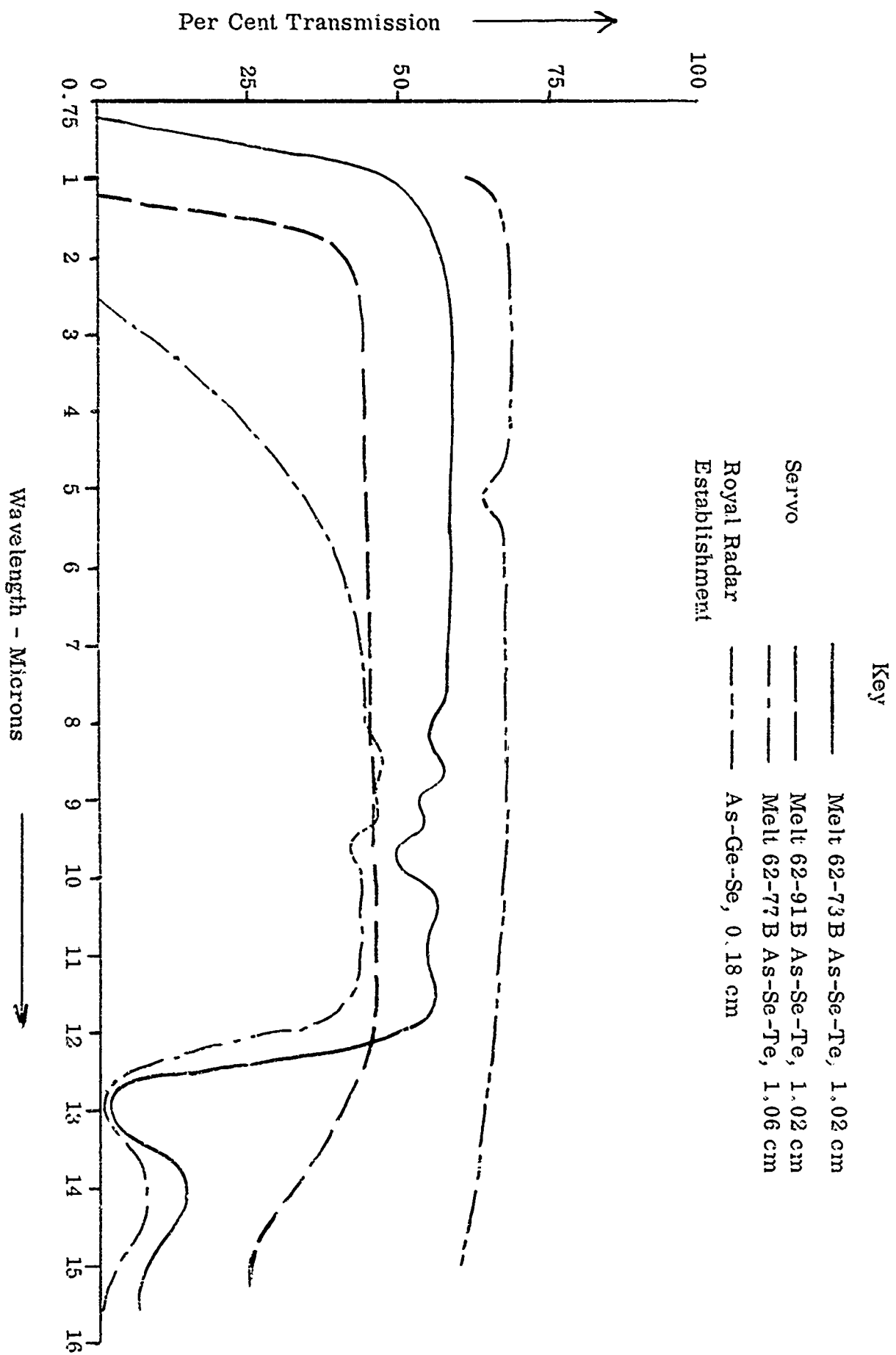


Figure 2

There are instrumental uncertainties in the recording of these transmission curves since the samples were of high refractive index material 0.4 inch thick. This causes serious defocusing in the sample beam without compensating, equally, the reference beam of the instrument. Sample 62-91B shows evidence of microscopic bubbles which might explain the overall decrease in transmission, but the absence of a 12.7 micron absorption in this glass is not adequately understood. It is considered that this sample may have been an experimental one to eliminate the presence of As_2O_3 . Consequently the overall spectral transmission figures must be regarded as the minimum, and in practice may be a little greater than recorded. This will be confirmed with the radiation pattern recording equipment. It is noteworthy that the samples ordered from Servo Corporation will be processed to minimize the 12.7 micron absorption and should show the higher transmission values of Figure 2 with transparency in the 13 micron region.

D. Fiber Drawing Experiments

The small samples of Servo glasses 62-73 B, 62-77 B and 62-91 B were obtained from the sponsor early in this program. It was anticipated that more careful environmental control was required in the drawing of these glasses than previously provided for the arsenic-sulphur glasses but it was considered valuable to proceed with fiber drawing experiments without this additional provision. The following combinations of glasses were used in these experiments:

<u>Coating Glass</u>	<u>Core Glass</u>
62-73 B	62-77 B
62-91 B	62-77 B

Preliminary experiments were conducted with the arsenic-sulphur glasses. The

results showed that the core glass did not flow as readily from the nozzle as the coating glass. This was attributed to the fact that the two crucibles, being approximately one quarter of the height of the crucibles used during the previous year, were constrained to be too close in temperature. With the larger crucibles, which were used earlier with success, the upper crucible was maintained about 100° F hotter than the lower crucible to provide the viscosity differences necessary to bring the core glass down the longer nozzle tube and maintain reasonable fiber core to coat ratios. The nozzles were redesigned before the arsenic-selenium-tellurium glasses were used so that the constriction through which the coating glass would flow was proportionately narrower. The three samples of arsenic-selenium-tellurium glass used in this work were not optimally chosen for core-coat compatibility and the differences in softening point proved to be greater than could be tolerated with the small compact crucible design. In this crucible design the temperatures in the core and coating glass reservoirs are equal (see Figure 3). Another factor which is of importance in the results obtained in this work is the short distance between core glass reservoir and nozzle, resulting in low hydrostatic pressure at the nozzle. This hydrostatic pressure is important when the crucible nozzles are heated, since it ensures that the glass descends in a solid plug which replaces all the air in the nozzle.

The most important observation in this preliminary work was the existence of many seeds in the drawn fibers. These seeds were oxidation particles which had occurred either at the surface of the reservoir melt, on the surface of each piece of cullet as it was melted at the beginning of the operation, or within the

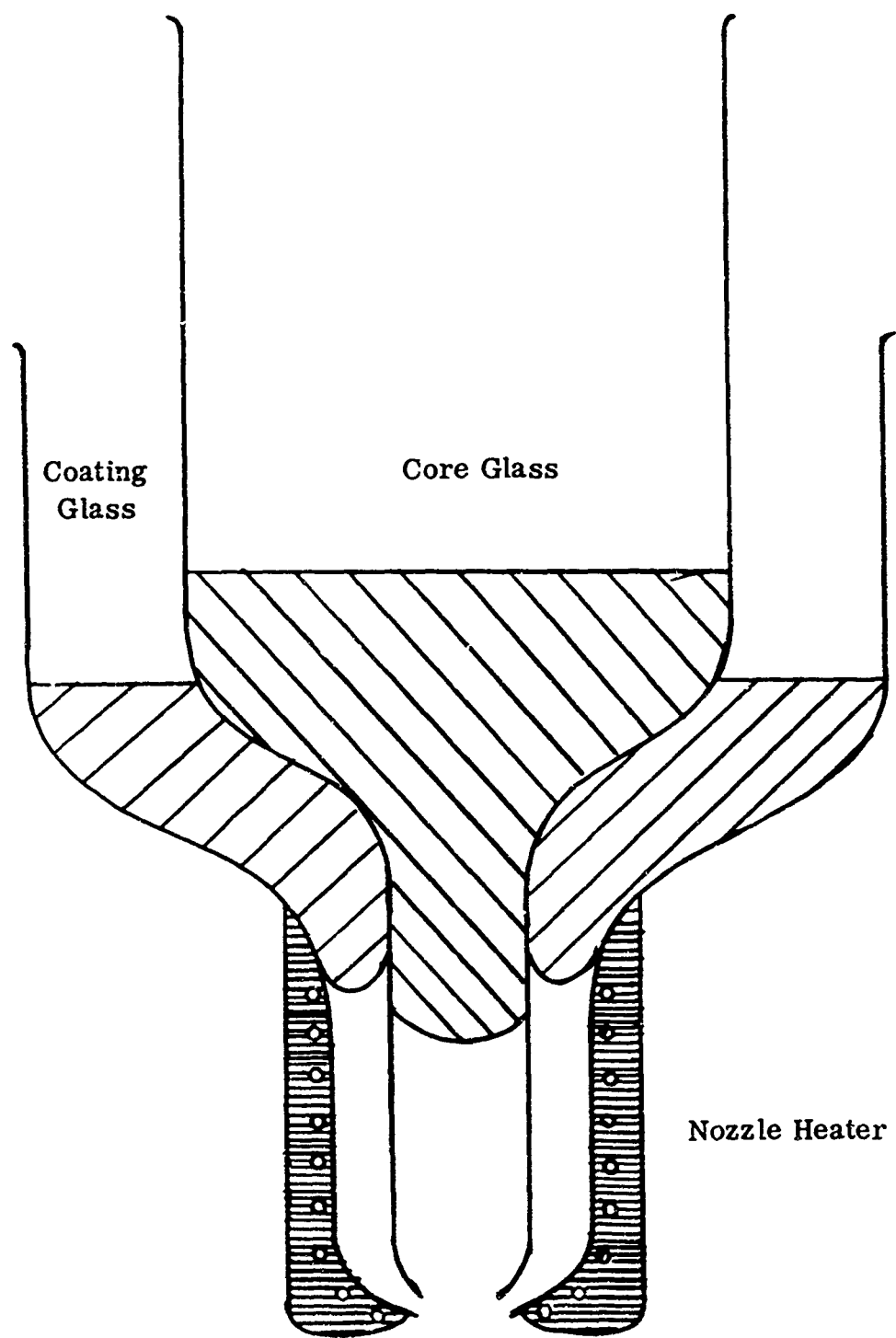


Figure 3 - Concentric Crucible

nozzle itself before the glass had reached the lower end of the down tubes. Melts 62-73 B and 62-77 B both drew into fine, flexible, comparatively strong fibers and it is anticipated that the vitrification problems will not therefore be serious. However with glass 62-91 B, after severe thermal cycling, devitrification occurred in substantial portions of the reservoir in the crucible. Information is awaited from Servo regarding this phenomenon since it may limit the utility of this particular glass in the fiber optics processes.

It may be concluded from this work that the temperatures of the two crucibles must be independent and that careful atmospheric control is of the utmost importance. Consequently the first, larger crucible to be constructed will have separate heating tapes for each half of the crucible, together with a third nozzle heater, each of which will be controlled by a separate temperature regulator. The crucibles will be mounted inside a glass bell jar in which a slight positive pressure of pure nitrogen will be maintained. A controlled flow of nitrogen will be directed from the bell jar into the nozzle area in an attempt to prevent oxidation within the nozzles. The results of future work in which this technique will be used will be reported as they become available.

III. FUTURE PLANS

The fiber drawing machine, the optical evaluation equipment and the first fiber production crucible will be completed within the next month. The glass samples from the Servo Corporation should arrive in two weeks, at which time the evaluation of these materials for their fiber optics drawing properties under suitably controlled conditions will be initiated. These evaluations should be completed during the next quarter and final decisions will be made on two or three glass combinations to be used during the remainder of this program. The optical evaluation equipment will be used to record data on thick bulk glass samples as well as on fiber samples as they become available.

APPENDIX

FAR INFRARED FIBER OPTICS MATERIALS SURVEY

APPENDIX

(U) FAR INFRARED FIBER OPTICS MATERIALS SURVEY

The properties of the As-S series of glasses are well known and have been widely reported. The infrared glasses considered in this survey must primarily satisfy the criterion of a longer infrared transmission range than these As-S series.

Oxide glasses have not been considered for this work since none of these is known to transmit to 7 microns even in very thin sections. In thicknesses of over 1 cm, few exhibit low absorption in the 2.7 to 6 micron range.

The discussions of the many non-oxide glass forming systems are derived from a variety of sources and, consequently, though some of the conclusions will be quantitative, some will only be qualitative. In addition to this, the techniques of preparing the glass samples and of recording the spectral transmission are by no means standard and the consequent variations between different sources for data on the same samples preclude serious quantitative conclusions.

Another feature of the transmission curves of these developmental glasses is the apparent effect of scattering, both of the Rayleigh and Mie type, which reduces the measured transmission. Whether this is in fact scattering, and if it is, whether the causes can be eliminated by more sophisticated preparation techniques, are not discussed in the majority of cases.

1. As-S (References 1 and 2) - These glasses were used in Reference 1 and are the basis from which improvements are to be made in this program.
2. Ge-S (Reference 3 and 4) - This glass has the same order of transmission

range as the As-S glasses. It is of no use beyond 11 microns, with strong indications of high reflectance and scattering effects at shorter wavelengths. Reference 4 shows the absorption coefficients of Ge_2S_3 which are in excess of 10 cm^{-1} at 12 microns and beyond. Below 11 microns, the coefficients are low.

3. As-S-Cl/Br/I (References 5 and 6) - Reference 5 gives detailed data on these glasses. They exhibit an absorption at 8 microns in common with As-S glasses and, between 8 and 14 microns, the general transmission profile is comparable to that for As_2S_3 . Although minor differences exist, notably in the positions of the absorption bands, it is evident that the glasses will be of negligibly better optical quality than As_2S_3 when used with path lengths of 1 cm or more. The absorption coefficient of these glasses is quoted to be about 20 cm^{-1} at 12 microns and, from the curves, it is not less than 5 cm^{-1} at wavelengths of more than 8 microns.

Reference 6 shows more data on the As-S-Br glass but, since this is shown qualitatively for a sample thickness of only 1 mm, it is of little value for this study.

4. As-S-Sb (Reference 7) - The transmission curves of this reference are somewhat diagrammatic and are for sample thicknesses of less than 2 mm. This glass shows increasing absorption from 9 microns onward which is to be anticipated from the presence of the As-S bonding.

5. As-S-Te (Reference 7) - The comments for the preceding glass apply to this one also.

6. Ge-P-S (Reference 4) - The absorption coefficients for these glasses are well above 10 cm^{-1} over the wavelength range 8 to 14 microns so are patently not suitable. As the phosphorus content approaches zero, (c.f. comments on Ge_2S_3) the transmission range extends. A further problem with glasses that

contain phosphorus is that the presence of free phosphorus renders the glasses chemically unstable.

7. Se (References 3 and 8) - Selenium exists in an amorphous form up to 35°C at which temperature it melts. Although the infrared transmission is good (α less than 0.5 cm^{-1}) to beyond 20 microns with the exception of small bands at 13.5 and 20.5 microns, the low softening point precludes its use in this work in environments of up to 100°C.

8. Ge-Se (References 9 and 3) - Reference 3 shows two glasses from this system to be, in 2 mm thicknesses, absorption free over the range 3 to 15 microns except for a moderate absorption at 13 microns. They postulate that this is the 13.6 micron band of Se shifted by the addition of Ge. Reference 9 also describes these glasses but allocates an absorption coefficient of up to 20 cm^{-1} at 13 microns and above 5 cm^{-1} at longer wavelengths. Reference 3 postulates that the 13 micron band may be accentuated by the presence of GeO_2 which does absorb at this wavelength. This is partly supported by the work on the As-Se-Ge system which will be described below.

9. Ge-Se-Tl/Sb/Bi (Reference 3) - The results of these glasses, all with less than 5 per cent of the third constituent, are close to those for the Ge-Se system. Worthy of note is the reported near absence of the 13 micron band for a 1.8 mm thickness of Ge-Se-Tl which becomes excessively strong on the addition of 0.025 per cent O_2 .

10. As-Se, As-Se-Te (References 10 and 11) - The As-Se glasses are special cases of the three component system As-Se-Te. Reference 10 gives the greatest

detail on this system and the conclusions are largely confirmed by other investigations. The glasses generally are absorption free from 3 to 12 microns. A narrow band is centered at 12.7 and a wide one at 16 microns.

If the 12.7 band could be eliminated, some of the glasses should have absorption coefficients of less than 0.5 cm^{-1} over the range 2 to 13+ microns. Reference 10 reports work aimed at eliminating the 12.7 micron band and, attribute it to As_2O_3 . This last assumption is justified and is supported by References 3 and 11. The As-Se glasses appear to lose the 12.7 band more readily than the As-Se-Te glasses, two of which are reported in Reference 10 which show no band structure from 2 to 15 microns.

The glasses described in this reference appear to possess a uniform absorption coefficient which varies very little over the range 2 to 15 microns. This non-dependence of the absorption coefficient on wavelength over 3 octaves strongly suggests scattering effects or inaccuracies in the transmission and reflection measurements--hopefully the latter.

11. As-S-Se (References 10 and 11), As-S-Se-Tl (Reference 7), As-S-Se-Te (Reference 12) - All these glasses show transmission characteristics between those for As-S and As-Se as would be predicted. The As-Se glasses that do not contain sulphur are, in general, more suitable than these.

12. As-S-Tl - Reference 13 gives great detail on the optical evaluation of this glass. The introduction to this article describes the glass as "optically clear from 1 to 23 microns in wavelength". However, on closer examination, it is seen that they really mean that the absorption coefficient is at least 10 cm^{-1} up to 10 microns beyond which it rises rapidly!

13. As-Se-Te-Cu/Ag/Sb/Cd/Bi (Reference 10) - The last two are not stable glasses and the other three are nowhere as transmissive as the base glasses As-Se and As-Se-Te.

14. As-Sb-Se (Reference 7) - This reference, using thin samples, claims that this glass gives good transmission of over 70 per cent from 2 to 18 microns with a single absorption at 13 microns. Although the data may be partially suspect, this could be of interest.

15. As-Se-Tl (Reference 7) - Absorptions up to 6 microns with fair transmission from 6 to 18 microns. No deep absorptions are evident in the latter range, but the transmission curve is not flat which implies some absorption.

16. Ge-As-Se (References 3 and 10) - Both the Ge-Se and As-Se systems produce glasses which possess only one absorption, that at 12 to 14 microns. The combination of these two binary systems results in a strong absorption at 12 to 14 microns and a weak one at 8. Reference 10 demonstrates that the 8 micron band can be reduced to negligible proportions in a 2mm path length but the 12 to 14 band, though it can be diminished, could not be eliminated. GeO_2 absorbs at 8 and 12 to 14 microns and As_2O_3 absorbs at 13 microns. It is reasonable to assume that the absorptions in the Ge-As-Se glass are primarily due to these oxides together with a fundamental absorption at 13 microns (c.f. Se).

17. Ge-As-Te (Reference 4) - One glass shown in this reference has a curve similar to the above but with the absorption narrowed and centered between 13 and 14 microns; otherwise, it is clear from 3 to 18 microns. Two similar glasses show absorption coefficients which are never lower than 1 cm^{-1} . These latter show a strong wavelength dependence which is reminiscent of Rayleigh

scattering. These latter glasses also show absorption peaks at 11 microns, and one of them at 6 microns. Clearly the data here is not self consistent. All that can be deduced is that there is an absorption at 13 microns and the absorption coefficient is probably less than 1 cm^{-1} outside this band over the range 5 to 18 microns.

18. Ge-P-Se (Reference 4) - The absorption coefficients for this glass are about 5 cm^{-1} from 4 to 16 microns, with no deep absorptions in that range. However, this is still fairly absorbant for our uses and, besides, the dangers of phosphorus bearing glasses are relevant for this glass.

19. Si-P-Te (Reference 4) - The absorption coefficients are between 5 and 10 cm^{-1} over the range 4 to 18 microns with a slight absorption (5 cm^{-1}) at 13 to 14 microns.

20. Si-S-Sb (Reference 4) - Not chemically stable.

21. Si-Se-Sb (Reference 4) - Strong absorptions at 9, 12 and 16 microns. At the absorptions, the coefficient rises to more than 20 cm^{-1} .

22. Si-As-Te (Reference 14) - The absorption coefficient is between 5 and 10 cm^{-1} with the exception of bands at 10 and 14 microns.

23. Si-As-Te-Sb (Reference 14) - For some reason, this glass appears to be less absorbing than the previous one, showing an absorption coefficient of less than 1 cm^{-1} from 2 to 12 microns rising to 5 cm^{-1} at the 14 micron absorption.

CONCLUSIONS

Based on the prerequisite that the selected glasses should represent a significant improvement in spectral transmission range over the As-S glasses

(No. 1), the following conclusions are evident.

1. Systems Nos. 2, 3, 4, 5, 6, 12 and 21 represent no improvement over No. 1; therefore, they will not be considered further.
2. Systems 7, 18 and 20 will not be considered further due to impracticable thermal or chemical properties.
3. Systems 13, 15 and 19 show some improvement over No. 1 but are all surpassed by similar, usually simpler systems so, if possible, these will be used as the least desirable possibilities.
4. Systems 8, 9, 10, 14, 16, 17, 22 and 23 emerge as those which should receive more examination than the preceding systems. Some of these represent small improvements over the As-S glasses and some seem more promising.

Systems 8 and 9, Ge-Se with or without small additions of other elements, will be considered together. There is some disagreement on the spectral transmission beyond 12 microns although, up to that wavelength, the glasses have low absorptions. Questions are: How much of the 13 microns absorption is due to GeO_2 ? Why is there no 13 micron absorption in the Ge-Se-Tl glass of Reference 3? If the 13 micron absorption is due to GeO_2 and can be eliminated, the absorption coefficients should be low from 3 to 15 microns.

System 10 is the one which has received the major attention of the Servo Corporation. The comments on this glass are similar to those for the preceding system, the absorption at 12.7 microns has been demonstrated to be caused by As_2O_3 and has been eliminated in some melts. If this elimination can be maintained in the fiber drawing process, this material can be useful over the range

2 to 15 microns. One possible problem is the existence of a small but constant absorption coefficient. The cause of this is unknown but it is thought that it is most likely to be caused by slight errors in the refractive index and/or absolute spectral transmission measurements.

On the assumption that glasses can be obtained with no bulk 12.7 absorption, the above two problems can only be evaluated on an experimental trial. This glass forming system has the advantage of availability which, if it is not surpassed in properties, makes it a possible good choice.

System 14 appears in a somewhat diagrammatic transmission curve, to have potential. However, if this is not borne out by other experimenters in written correspondence, this should be dropped. The reasons for this are: The only reported investigation is Russian, so supply, consultation on fabrication processes or confirmation of results are out of the question; the data is not quantitative, meaning that detailed conclusions on actual transmission are suspect; and from an intuitive point of view, the As-Se glass should, if anything, be better than the As-Se-Sb glass in transmission range due to the smaller number of possible configurations of molecular arrangement in the former, leading to fewer absorptions and less severe perturbations.

System 16 is the result of adding Systems 8 and 10. Consequently, it is to be expected that the resultant absorptions will be at least as numerous and as deep as those in the two constituents. This is in fact confirmed, the major absorption is at 12 to 14 microns. The exploration of this system should await the results of producing systems 8 and 10 with no absorptions in the 12 to 14 micron range. It might then be possible to produce this system with the same

transmission range but otherwise with different properties.

System 17 suffers primarily from a constant background absorption which is not explained. If this were not present, the glass should be usable over the range 3 to 18 microns with an absorption at 13 microns. The cause of this absorption is also not investigated but in the light of work performed by other investigators, an oxide impurity might be suspected. Further inquiries as to the cause of this absorption and the constant background absorption are worth making.

Systems 22 and 23 show an example of why the data should be handled judiciously. The Se-As-Te glass as it stands (22) is least useful of this first selection of glasses but the addition of a small quantity of Sb apparently radically changes the situation (N.B., Sb did this once before, viz. 14). Further elucidation should be sought.

RESULTS

1. Systems 8 and 9 (Ge-Se with additions). Through correspondence, Dr. J. A. Savage of Royal Radar Establishment, Malvern, England, informs us that he has produced an As-Se-Ge glass which is non-absorbing from 1.5 to 15+ microns with the exception of a small band at 4.5 microns. He is in the process of persuading an English company to undertake its manufacture but feels that none will be available in the near future. His enclosed transmission curve is shown in Figure 2.

2. Systems 10, As-Se-(Te). Samples ordered from Servo Corporation.

3. Systems 14, 22 and 23. The data of Reference 7 with respect to System 14 is considered suspect. Although it was not able to prove this, the general

rule that the addition of further components to a glass forming system should increase the complexity of the infrared absorption spectrum is sufficient to make further investigation not worth pursuing.

No explanation has been offered for the better transmission range of System 23 over that of System 22. This type of cross comparison of experimental results is very rarely performed and when it is, anomalies such as this are often difficult to solve. This point will be pursued.

4. It appears that Ge-As-Se and Ge-Se systems are being investigated together. The results mentioned above from Royal Radar Establishment hold promise for the Ge-As-Se glasses. Although no glasses from this system are currently available in such a high quality, a careful watch will be kept on progress in this area.

REFERENCES

1. Kapany and Simms, "Infrared Fiber Optics Investigations", AL-TDR-64-98, Optics Technology, Inc., Belmont, California, Contract AF 33(657)-11480, and Kapany and Simms, "Fiber Optics. XI. Infrared Region", paper presented at the Optical Society of America Spring Meeting, Washington, D.C. (J. Opt. Soc. Am., 54, 4, (1964) Abstract WG 17).
2. Servo Corporation of America, data sheet on "Servofrax".
3. Savage and Nielson, "Preparation of Glasses Transmitting in the Infrared Between 8 and 15 Microns", Phys. Chem. Glasses, 5, 3 (June 1964).
4. Second Semi-Annual Technical Report for "New High Temperature Infrared Transmitting Glasses", Texas Instruments, Dallas, ONR Contract Nonr 3810(00).
5. Deeg, "Physical Properties of Glasses in the System Arsenic-Sulphur-Halogen", Advances in Glass Technology, (Plenum Press, New York), 1962.
6. Fischer and Mason, "Properties of an As-S-Br Glass", J. Opt. Soc. Am., 52, 6, p. 721, (June 1962).
7. Kolomiets and Pavolv, "Vitreous Semiconductors VIII.", Fiz. Tverdogo Tela. 2, 4, (April 1960).
8. Semiannual Technical Summary Report, "Properties of Glasses Transmitting in the 3 to 5 and 8 to 14 Micron Window", Servo Corporation of America, ONR Contract Nonr 4212(00).
9. Hilton, Jones and Brau. "New High Temperature Infrared Transmitting Glasses", Presented to the 10th IRIS at Fort Monmouth, New Jersey, October 1, 1963.
10. "Investigation of Long Wavelength Infrared Transmitting Glasses", ASD-TDR-63-552, Servo Corporation of America, Contract AF 33(657)-8560, June 1963.
11. Vashko, et al, "Absorption Spectra of Glasses of the System $As_2S_3 - As_2Se_3$ ", Opt. Spectr. 12, 2, p. 149 (1962).
12. Stierwalt, Bernstein and Kirk, "Measurement of the Infrared Spectral Absorbance of Optical Materials", Applied Optics., 2, 11, (November 1963).
13. McDermott, Powell and Stack, "The Optical Constants of 30% As - 34% S - 36% Te", IR Phys., 1, p. 167 (1961).
14. Hilton and Brau, "New High Temperature Infrared Transmitting Glasses", IR Phys., 3, p. 69 (1963).